Nitz & Stair, Jr.

Current Division Between Alternators in Parallel

Electrical Engineering

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CURRENT DIVISION
BETWEEN
ALTERNATORS IN PARALLEL

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

INGO CHARLES NITZ and JACOB LEANDER STAIR, JR.

ENTITLED CURRENT DIVISION BETWEEN ALTERNATORS IN PARALLEL

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

Morgan Brooks,
Instructor in Charge.

APPROVED: Morgan Brooks.

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CONTENTS.

INTRODUCTION.

According to some preliminary investigations carried on by Professor Morgan Brooks and M. K. Akers, it was at first thought that by the method herein described, the load on two or more alternators operating in parallel could be divided equally or in such proportion as desired. It has been concluded, however, that nothing but the driving forces could effect the division of load between alternators in parallel, and that if the driving force of one machine was less than that of another, the former could not carry as large a load as the latter. It was thought that the same theory and method would apply to the division of current irrespective of the power load division.

OBJECT.

The object of these tests was to investigate the effect of transformers, connected in series with the machines, as shown on page 12 , upon the division of the current output between two alternators operating in parallel under various conditions. These conditions were to include the following:

1. Alternators running under increasing load with driving forces equal and (a) with excitation of fields kept constant, and (b) with terminal voltage constant.

2. Alternators running under constant load with the driving forces equal and with the field excitation of one machine varying.

3. Alternators running under constant load with constant field excitation and with the driving force of one machine

varying.

Similar tests were also to be made without the transformers in the alternator circuits, and the results compared with those obtained when using the transformers. Lastly a 3 to 2 current ratio test was to be performed with one transformer.

DESCRIPTION OF APPARATUS.

The transformers used in these tests were two of special design which were built by the Wagner Electric Co., for use in the University power plant. Each was of 4 kilowatt capacity with a primary potential of 45 volts and a secondary potential of 30 volts. The coils were of a few turns of very heavy wire, making the resistance very low, the primary resistance being .0058 ohm and the secondary resistance, .0024 ohm.

Machine No. 1 was the 220 volt, 2 or 3 alternating current generator No. 95584, manufactured by the General Electric Company. This machine, 7.5 K.W. in capacity, has a six pole revolving field and therefore had to be run at a speed of 1200 R. P. M. to produce a frequency of 60 cycles per second.

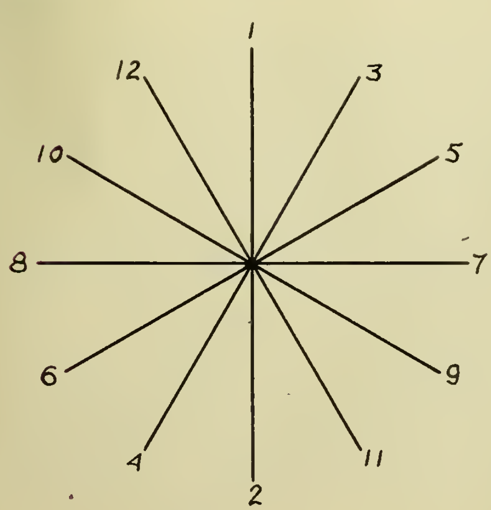


Fig. 1.

The armature has six coils so arranged that their electromotive force vectors are 30° apart as shown in figure 1. The tests were run at 110 volts single phase, and in order to obtain a greater output from the machine, than could be obtained from one coil, three

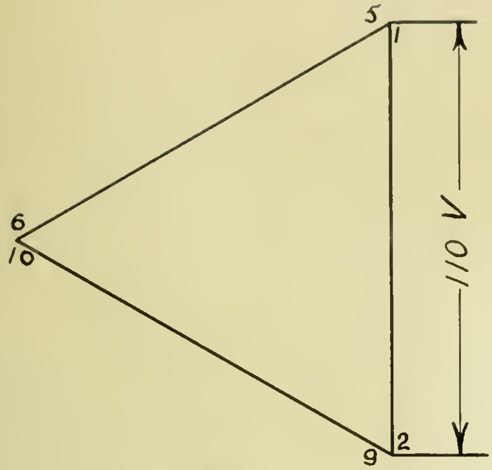


Fig. 2.

coils were connected as for three phase delta (Fig. 2), thus giving two branches in which to generate the current. This decreased the armature impedance and thereby decreased the IZ drop in the armature.

Alternator No. 2 was a 5 pole inductor alternator of 7.5 K.W. capacity built by Durfee and Drew, '06. This machine has two separate armature windings which could be connected in parallel or in series for generating 110 or 220 volts. Its speed was kept at 720 R. P. M. to produce a frequency of 60 cycles per second.

Alternator No. 1 was driven by a 15 H.P., 4 pole, 220 volt Bullock motor. The motor was shunt wound and had a normal speed of 110 R. P. M.

Alternator No. 2 was driven by a 15 H. P., variable speed, 4 pole, 220 volt Westinghouse motor which was also shunt wound.

A reactance coil with an air core was used to aid in holding the machines in step, the primary being stationary and the short circuited secondary being so arranged that it could be slipped in or out of theprimary to change the impedance as desired. The coil had a resistance of .527 ohm and an impedance of 4.23 ohms making the angle between current and pressure equal to 82°50'. This current would therefore be nearly wattless.

THEORY AND METHOD.

Before taking up the method for the adjustment of load current between alternators, it may be well to review some of the generally accepted ideas, as given by Dr. Steinmetz and others, of the conditions that affect parallel operation.

There are a number of conditions that determine the successful operation of alternators in parallel. Among them are the following, differences in wave form and the effect of the higher harmonies, differences in the characteristics of the two machines, inequalities in driving force, variations in excitation, and the reactions due to armature current.

The effect of differences in wave form between two machines operating in parallel is to cause a circulating current. Even when the machines are similar the fundamentals may be closely in phase; but if the similar harmonies are not in phase a current is caused to pass between the machines.

Owing to differences in the regulation of two machines there may be a circulating current at certain loads, while at other loads the machines operate with no cross current whatever. The difference in the characteristics causes inequalities in the voltage of the machines.

The driving force is probably the most important factor to be considered. Inequalities in this respect tend to give rise to inequalities in frequency. The result is that circulating currents are caused which transfer energy from the machine whose driving power tends to increase its speed to the other machine, thereby causing the load on the first machine to in-

crease. At a light load or no load the cross currents cause one alternator to drive the other as a synchronous motor, while for the condition of load the machines do not share the load in proportion to their capacities.

The prime mover does not maintain a constant speed for all loads but nevertheless, the two machines that are operating in parallel must have the same frequency. The loads on the generators will so adjust themselves as to give a speed that corresponds to the same frequency. It is then seen that the division of load between alternators not rigidly connected mechanically depends almost exclusively upon the speed regulation of the prime movers. This speed regulation must be the same for the prime movers of each generator to divide the load in proportion to their capacities. Hence, if two machines are operating together and one of the engines governs more closely than the other, the alternator with the better governed prime mover will assume more than its share of the load at full load and less than its share at light load.

With customary centrifugal type of governor the speed varies inversely with power. With some form of electrical governing, power might be increased without decrease of speed.

It is sometimes supposed that the division of load between alternators can be determined by adjusting the relative field strengths of the two machines. As an example, take two similar alternators direct connected to two steam engines. These machines will, when operating in parallel, make with mathematical exactness the same number of revolutions per minute. If the load is 500 kilowatts, and the governor of one engine admits

sufficient steam to generate 100 kilowatts at the same speed that the governor of the other admits sufficient steam for 400 kilowatts, the load will divide itself in this ratio, no matter what may be done with the generator fields, either before or after synchronism. It is evident that a change in the relative field strengths of the two alternators can in no way affect the governors of the engines. Thus the division of load does not depend on the relative strength of the current in the alternator fields. If the load could be divided by increasing the strength of one field and decreasing that of the other, the law of the conservation of energy would be violated, since no change has resulted in the position of the engine cut-off. As long as the indicated horse-power of the prime movers remains the same, the output of one cannot be materially raised or that of the other lowered. When there is a difference in the exciting currents in the fields, the machines adjust themselves to practically the same field strength. This is done by an exchange of wattless cross currents that pull down the voltage of the machine with the stronger field, and "boosts" the voltage of the machine with the weaker field until the two approach equality. The generally accepted idea, then, is that the adjustment of load division depends not upon the relative field strength either before or after the machines are in parallel, but upon the load-speed characteristics of the prime movers.

Armature reactions also play a part in the successful operation of alternators in parallel. The lower the armature reaction, hence the closer the regulation of the machines, the

more sensitive they are to variations in field excitation. In cases of low armature reaction the synchronizing power may be so large as to require careful adjustment before the machines are thrown together, in order to prevent excessive circulating currents. On the other hand, for machines of high armature reaction the synchronizing power may not be sufficient to keep the alternators in step when heavy overloads occur. Hence, it is not desirable to have too low or even too great an armature reaction when machines are to be operated in parallel.

The conditions reviewed above that affect the load division will also have much to do with the division of load current between the machines. It is the latter with which we are concerned in this investigation.

The device used for effecting the division of load currents between two or more alternators running in parallel consists essentially of transformers T_1 and T_2 connected as shown in the figure on page 12. The primaries of the transformers are connected in circuit with one line terminal of the machine, while the secondaries are connected in series forming a closed circuit. All the transformers have the same number of turns in the primary, which is designed to carry a current that is in direct proportion to the full load current of the machine in whose circuit it is connected. The secondaries have the number of turns that is proportional to the share of the current that its corresponding primary is to carry. It is evident, since the secondaries are all connected in series, that the same current will flow in all.

This method for load current division also employes a synchronizing coil that will hold the machines in step independent of thevalue of the transformer inductance. The synchronizing coil must be placed across the terminals of the machines. The coil has such an impedance as will allow enough synchronizing current to flow to hold the machines in step. A sufficient cross current would not flow were the transformers between the machine and the reactance coil.

The operation of the device for the division of load current is as follows:- When currents proportional to the capacities of the machines are flowing through the primaries, the transformers will be non-inductive, since the ampere-turns of the primary and secondary are equal. Therefore, for these conditions practically no electromotive force exists at the terminals of the transformers. Just as soon, however, as there is any change in the value of the current flowing in either primary, without a corresponding change in the other, the transformers are no longer non-inductive, and the current flowing from the machines is opposed by the reaction of its primary. When the current in the primary coil changes it causes a corresponding change in the current from all the generators, through the short-circuited secondaries of the transformers. The proper proportion of load current is thereby restored, and each machine gives out a current that is proportional to its capacity. The effect is the same when any change occurs in the driving force or excitation of either machine.

The fundamental principle, therefore, of the load cur-

rent division method is to have transformers so connected as to be approximately non-inductive so long as the desired division of load current exists, but automatically inductive when the proper division is disturbed, whereby a satisfactory balance of the load currents is restored.

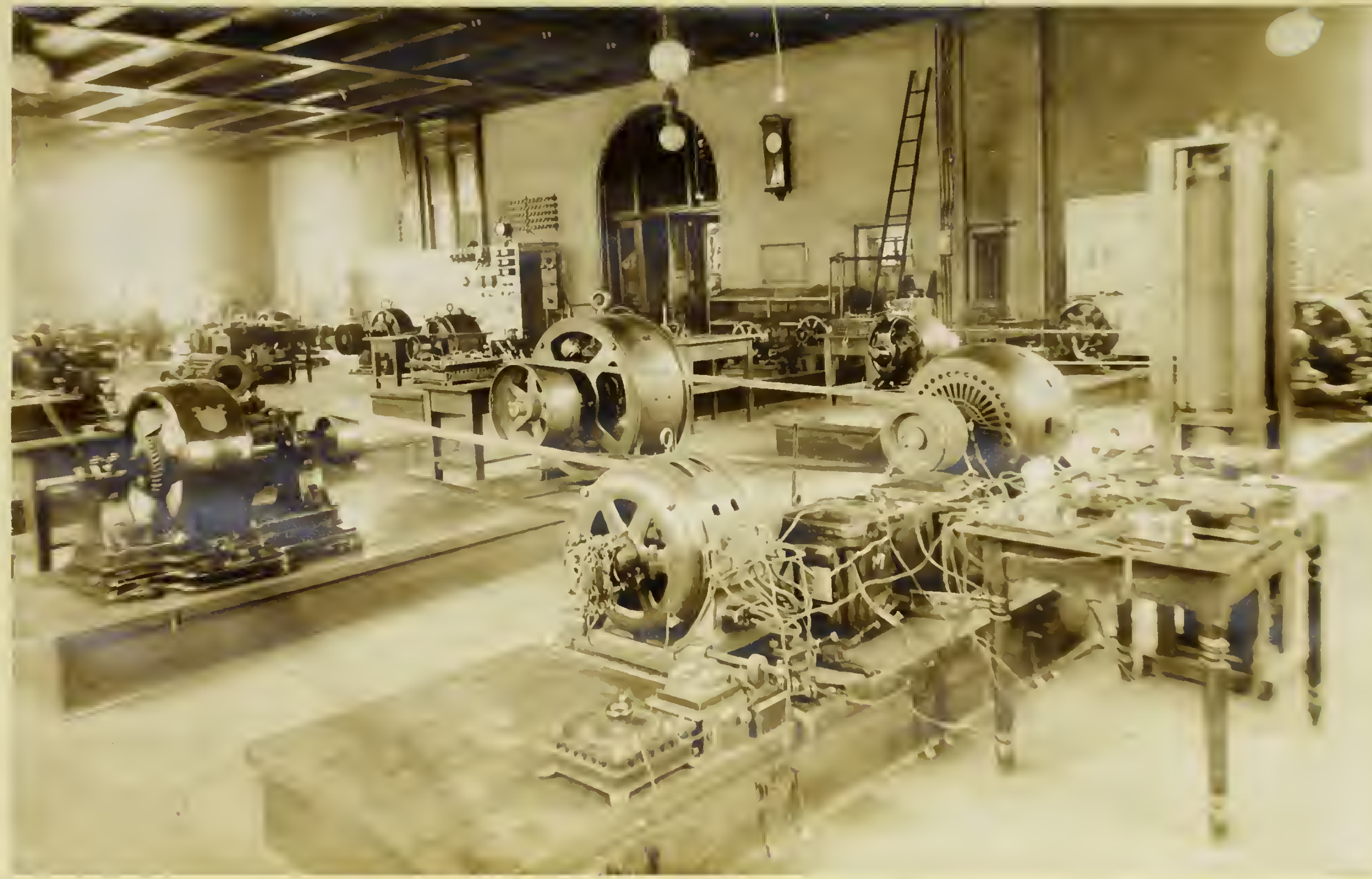
ARRANGEMENT OF APPARATUS.

The diagram of connections on page 12 shows the leads from the alternators to the load consisting of lamps. Nearest to the machines is placed the synchronizing bus bar with the synchronizing lamps and the reactance coil. The transformer primaries were connected in corresponding leads of the two alternators, and their secondaries were short circuited thru each other in such a manner that the pressures induced in them would aid one another in causing a secondary current to circulate. S_{sc} S_{sc} were switches for short circuiting the transformers, and S_{co} S_{co} were switches for cutting the transformers out of circuit. Thus when the former were open and the latter closed, the transformer primaries were in circuit, and when the former were closed and the latter open, the transformers were cut out of the alternator circuits. S_m S_m were main switches connecting the machines to the main bus bars thru the indicating ammeters and wattmeters. This method of connecting the transformers, which were or equal number of turns, should give an equal division of the current.

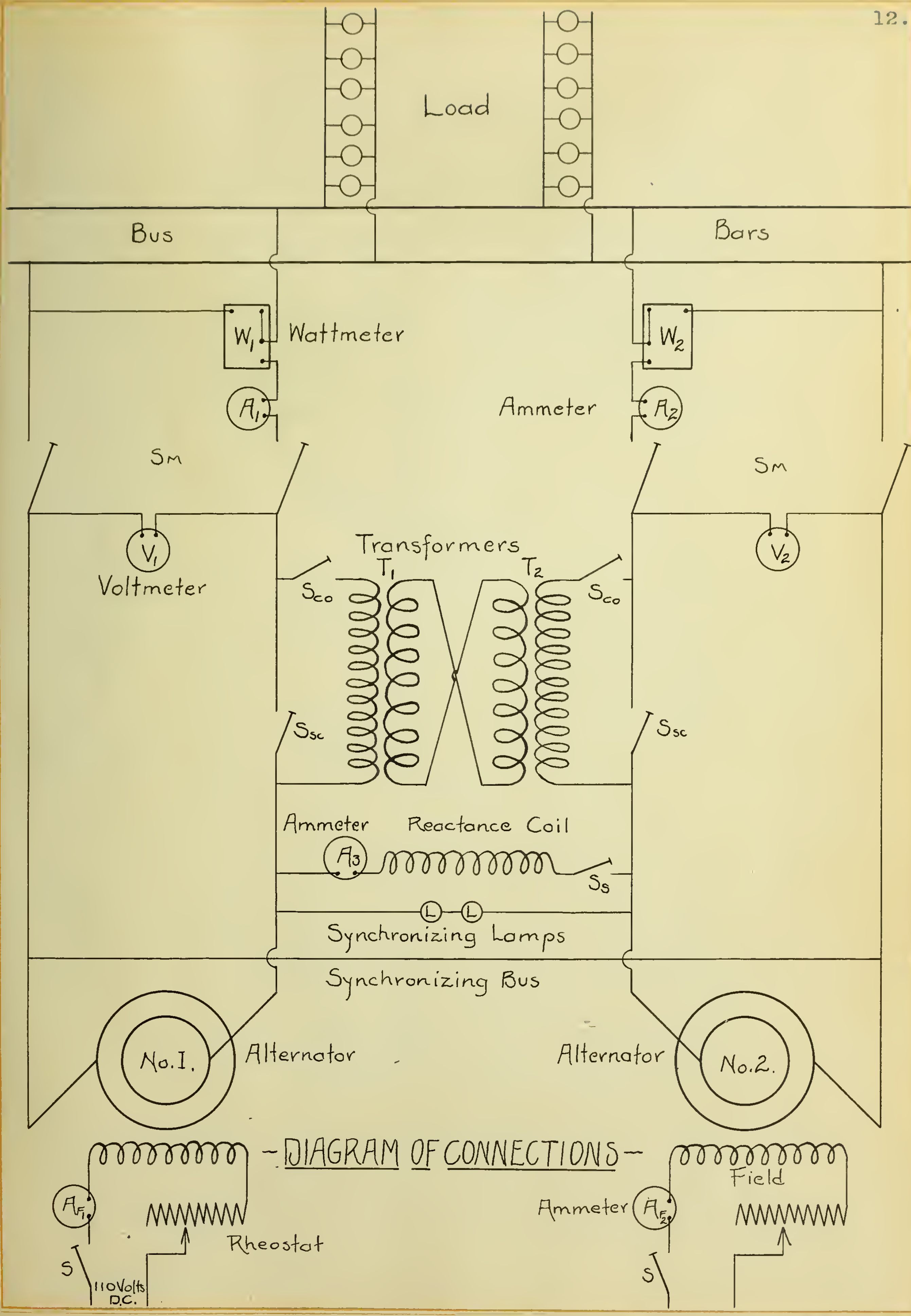
OPERATION AND DISCUSSION OF TESTS.

In each case the machines were brought up to synchro--nous speed and excited to generate 110 volts before they were connected in parallel by closing the synchronizing switch S_s. The main switches S_m S_m were then closed, connecting the machines to the main busses.

The object of test No. 1 was to determine the division of current between the two alternators under various loads from



— View Showing Current Division Apparatus. —

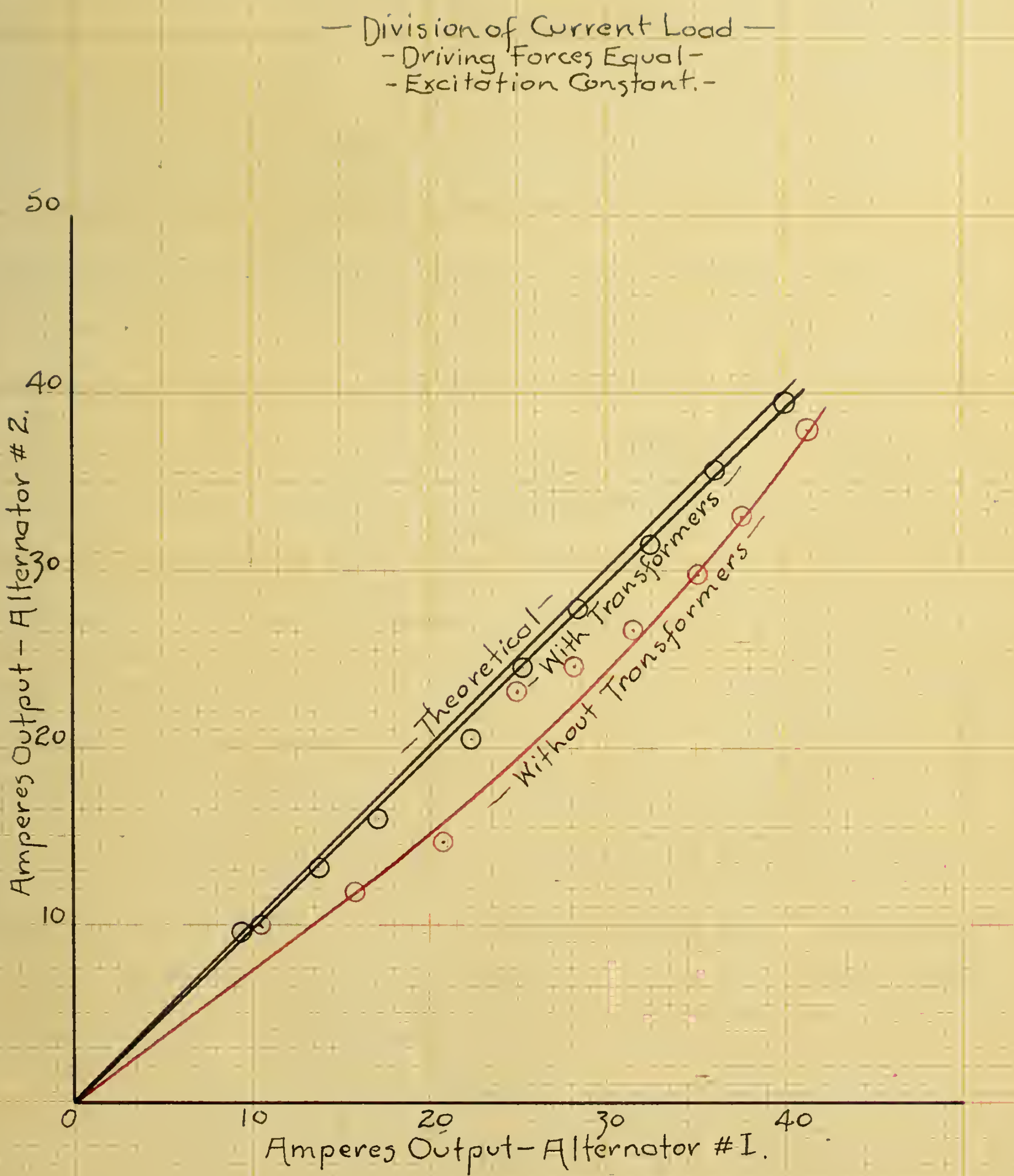


-DIAGRAM OF CONNECTIONS-

— Data for Load Current Division —

Load increasing, with driving forces equal and field excitations constant.

	No. of reading	Alternator No. 1 Current Output Amperes.	Alternator No. 1 Power Output K.W.	Alternator No. 1 Pressure in Volts	Alternator No. 2 Current Output Amperes	Alternator No. 2 Power Output K.W.	Alternator No. 2 Pressure in Volts.	Current thru Reactance Coil in Amperes.
— With Transformers —	1	0	0	109.0	0	0	109.0	0
	2	9.40	1.01	106.8	9.5	.93	106.8	"
	3	13.80	1.50	105.7	13.2	1.36	105.7	"
	4	17.2	2.02	104.8	16.0	1.67	104.8	"
	5	22.4	2.38	103.0	20.5	2.02	102.6	"
	6	25.3	2.65	102.0	24.5	2.41	101.5	"
	7	28.4	2.90	100.6	27.9	2.75	99.8	"
	8	32.4	3.29	99.3	31.5	3.03	98.6	"
	9	36.1	3.58	96.6	35.7	3.43	95.6	"
	10	40.0	3.82	94.0	39.5	3.60	93.2	"
— Without Transformers —	1	0	0	109.0	0	0	109.0	0
	2	10.5	1.16	107.3	10.0	.92	106.5	"
	3	15.8	1.75	107.0	11.8	1.16	105.5	"
	4	20.7	2.26	106.3	14.6	1.50	104.5	"
	5	25.0	2.63	105.6	23.2	1.91	103.8	"
	6	28.1	2.98	103.5	24.6	2.27	101.3	"
	7	31.5	3.26	102.2	26.6	2.67	100.0	"
	8	35.1	3.59	101.5	29.7	2.91	98.5	"
	9	37.5	3.86	100.5	33.0	3.21	97.0	"
	10	41.3	4.12	98.3	38.2	3.53	94.5	"


— Division of Current Load —
- Driving Forces Equal -
- Excitation Constant. -
Amperes Output - Alternator # 2.
Amperes Output - Alternator # I.
0
10
20
30
40
50
— Theoretical —
— With Transformers —
— Without Transformers —

-PLATE I-

0 to 40 amperes, with the driving forces on the two machines equal and the field excitation constant. The data on page 13 show the power and current output and the pressure supplied by each alternator. With the transformers in the circuit it was easy to adjust one motor field and keep the driving forces equal, because any difference in driving forces was immediately shown by current circulating thru the reactance coil circuit. Without the transformers this was not possible because the circulating current would take the path of least impedance which was through the bus bars. Ths slight inequality of driving forces with the increase of load, was due to the difference in the speed load characteristics of the motors. The curves on plate I show that the division of current was nearer to the theoretical ratio when using transformers than when they were not in use. The advantage of having a better adjustment of driving forces may have caused this result. The transformers, on the other hand, caused a larger drop in the pressure supplied as the load was increased from 0 to about 40 amperes. This greater drop is due to the impedance of the transformers which as soon as the primary currents were slightly different, became of such values as to produce an appreciable IZ drop that would have been more noticeable had it been in phase with the current.

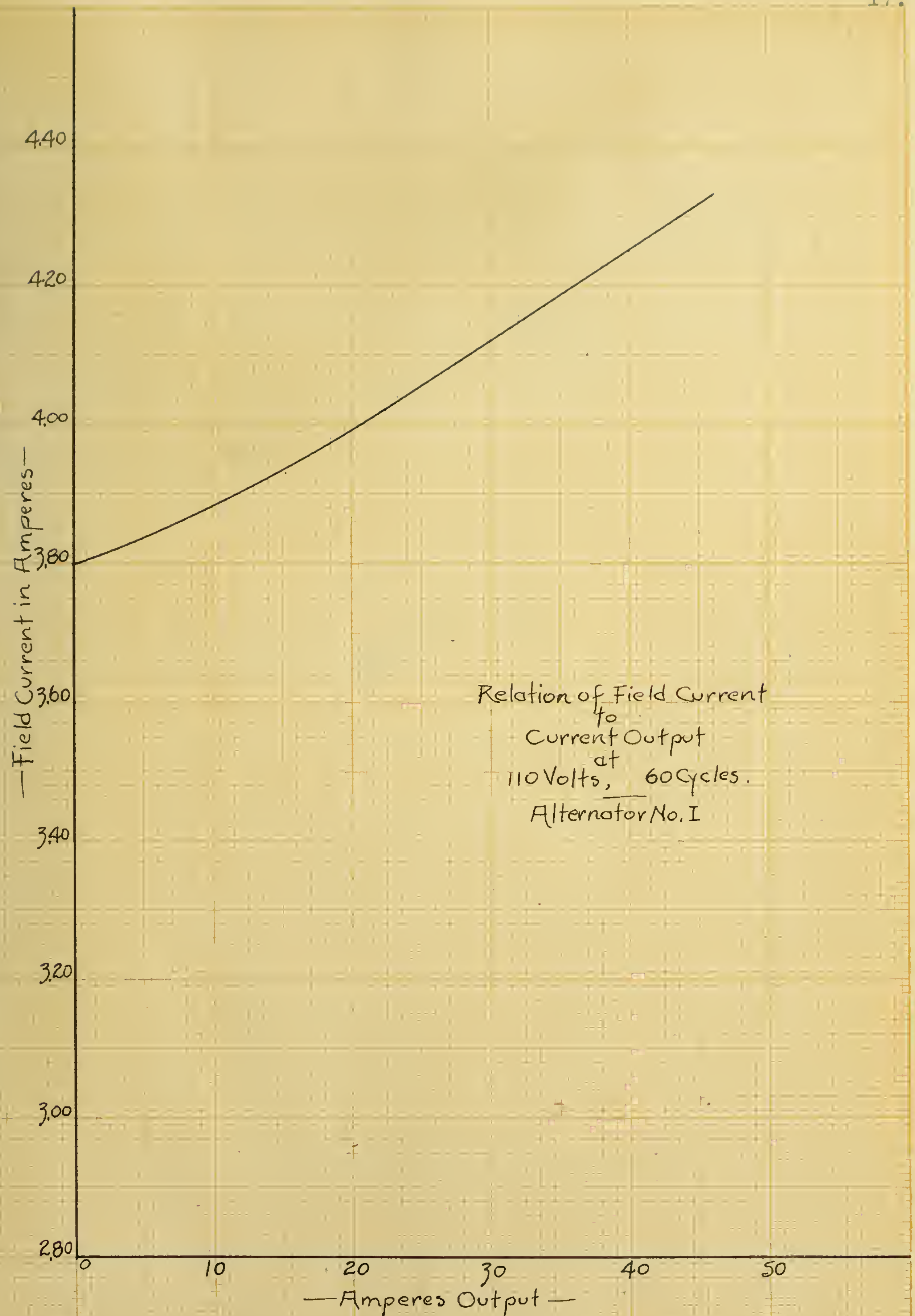
In part (b) of test I, it was desireable to keep the terminal pressure at 110 volts to give a condition more nearly that of actual power plant operation. To do this and keep the two alternators excited in equal proportion, that is, to force each one to generate 110 volts at all loads, the data on page 16

— Data for Excitation Curves —

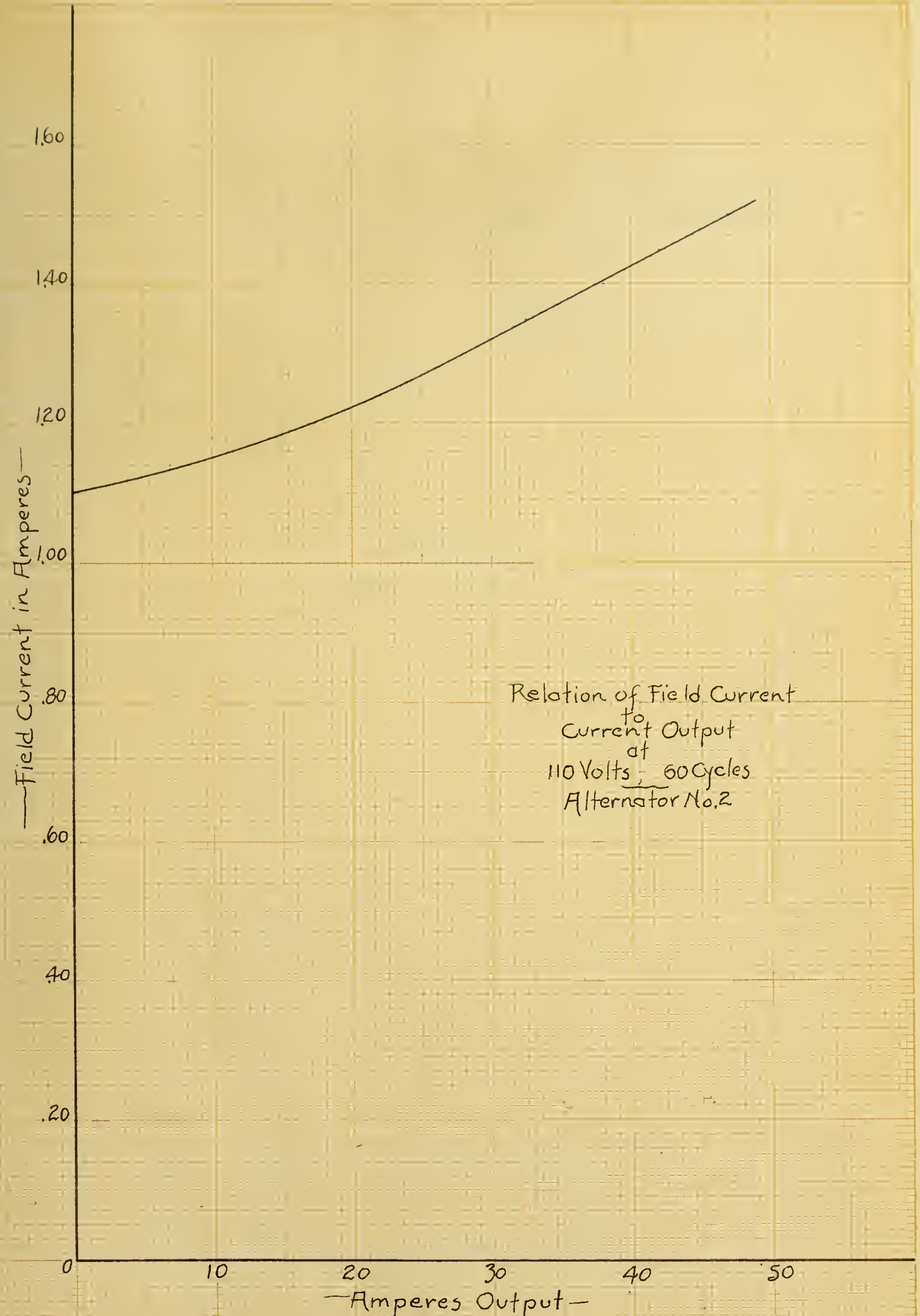
Machines operating separately, at 110 Volts

Load increasing.

Alternator No 1.			Alternator No. 2		
Terminal Pressure Volts	Current Output Amps.	Field Current Amps.	Terminal Pressure Volts	Current Output Amps.	Field Current Amps.
110	0	3.80	110	0	1.10
"	6.7	3.85	"	7.0	1.14
"	10.5	3.88	"	10.0	1.18
"	15.2	3.93	"	13.6	1.21
"	18.5	3.98	"	18.5	1.23
"	23.3	4.04	"	23.4	1.26
"	27.8	4.10	"	28.2	1.31
"	32.3	4.15	"	32.5	1.35
"	36.2	4.20	"	37.5	1.40
"	40.0	4.25	"	42.0	1.45
"	44.2	4.30	"	47.0	1.50


4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
2.80
—Field Current in Amperes—
0
10
20
30
40
50
—Amperes Output —
Relation of Field Current
to
Current Output
at
110 Volts, 60 Cycles.
Alternator No. I

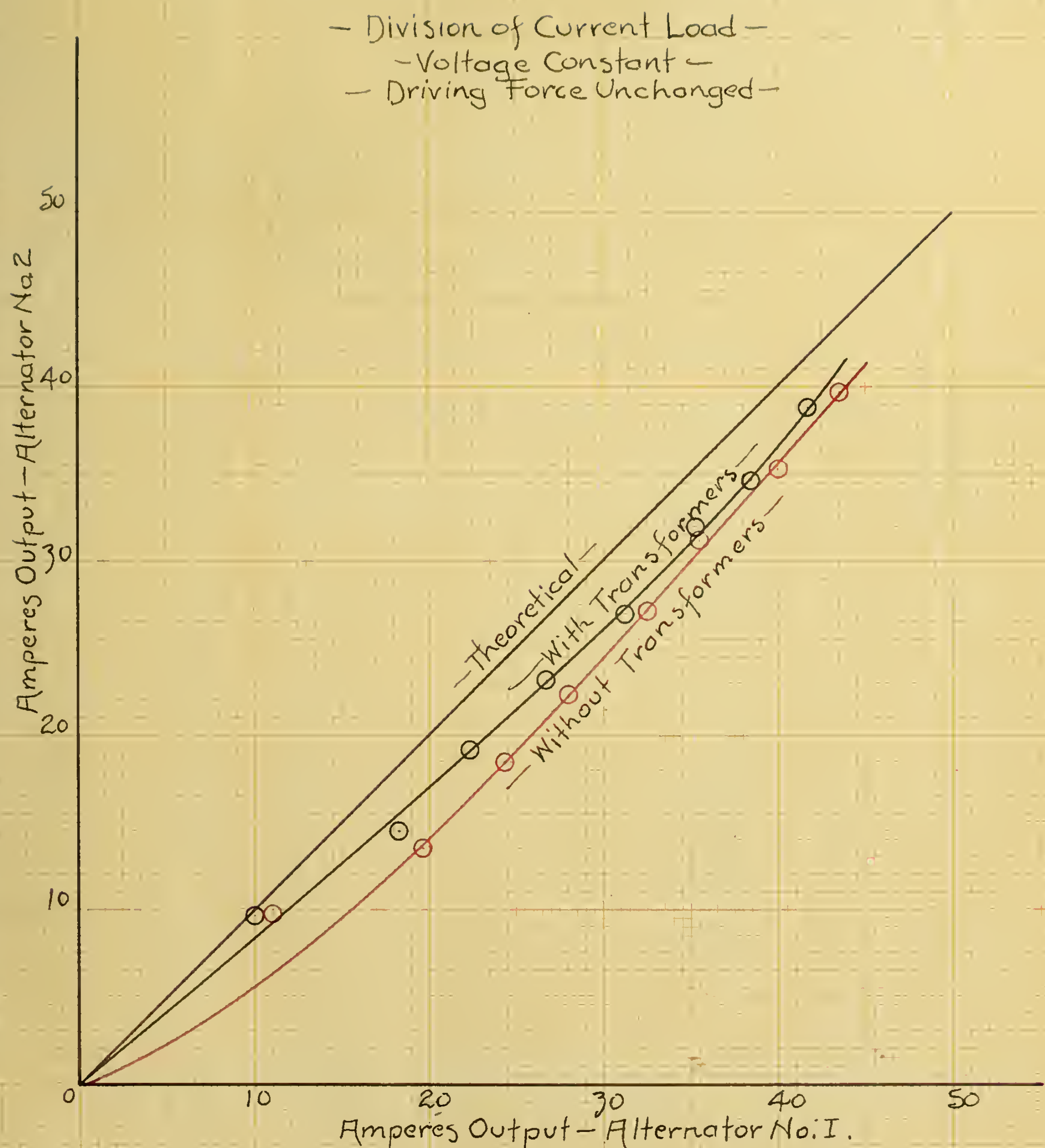
-PLATE II-


1.60
1.40
1.20
1.00
.80
.60
.40
.20
0
10
20
30
40
50
—Field Current in Amperes—
—Amperes Output—
Relation of Field Current
to
Current Output
at
110 Volts, 60 Cycles
Alternator No. 2

— Data for Current Load Division —

Load increasing, with driving forces unchanged and pressure constant at 110 Volts.

	No. of reading	Alternator No 1.			Alternator No. 2			Current thru Reactance Coil in Amperes.
		Current Output Amps.	Power Output K.W.	Pressure in Volts.	Current Output Amps.	Power Output K.W.	Pressure in Volts.	
— With Transformers —	1	0	0	110	0	0	110	1
	2	10.0	1.14	"	9.6	1.06	"	2
	3	18.3	2.11	"	14.5	1.63	"	6.3
	4	22.3	2.54	"	19.1	2.09	"	9.7
	5	26.7	3.02	"	23.2	2.56	"	10.5
	6	31.2	3.46	"	27.0	2.93	"	11.6
	7	35.3	3.91	"	32.0	3.42	"	13.2
	8	38.5	3.33	"	34.7	3.66	"	13.5
	9	41.7	4.67	"	38.9	4.13	"	12.4
— Without Transformers —	1	0	0	110	0	0	110	0
	2	11.0	1.37	"	9.7	.84	"	0
	3	19.7	2.30	"	13.5	1.59	"	0
	4	24.3	2.74	"	18.5	2.04	"	0
	5	28.0	3.14	"	22.3	2.43	"	0
	6	32.5	3.72	"	27.1	3.00	"	0
	7	35.5	4.08	"	21.2	3.39	"	0
	8	40.0	4.57	"	35.3	3.85	"	0
	9	43.5	4.91	"	39.6	4.15	"	0


— Division of Current Load —
— Voltage Constant —
— Driving Force Unchanged —
Amperes Output — Alternator No. 2
Amperes Output — Alternator No. I.
— Theoretical —
— With Transformers —
— Without Transformers —
0
10
20
30
40
50

-PLATE IV-

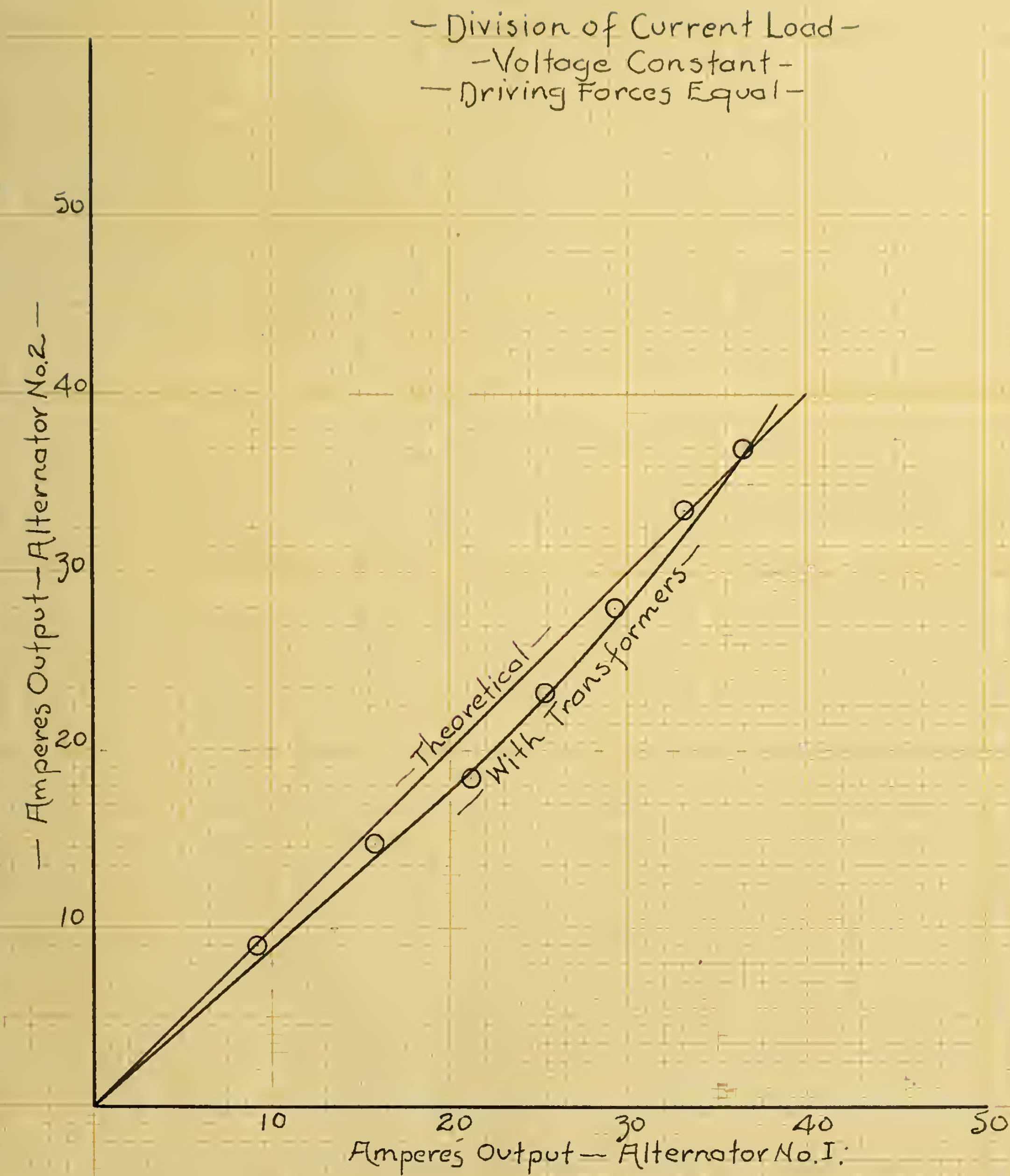
— Data for Current Load Division —

Load increasing, with driving forces equal

and Pressure constant at 110 Volts.

— With Transformers —

No. of Reading.	Alternator No.1			Alternator No.2			Current thru Reactance Coil in Amperes.
	Current Output Amps.	Power Output K.W.	Pressure in Volts.	Current Output Amps.	Power Output K.W.	Pressure in Volts.	
1	0	0	110	0	0	110	0
2	9.2	1.06	"	9.0	.95	"	0
3	15.8	1.78	"	14.7	1.61	"	0
4	21.2	2.44	"	18.4	2.01	"	0
5	25.4	2.86	"	23.2	2.45	"	0
6	29.2	3.31	"	28.0	3.07	"	0
7	33.2	3.76	"	33.5	3.65	"	0
8	36.5	4.06	"	37.0	3.95	"	0



— Division of Current Load —
— Voltage Constant —
— Driving Forces Equal —
— Theoretical —
— With Transformers —
— Amperes Output — Alternator No. 2 —
Amperes Output — Alternator No. I.
10
20
30
40
50

- PLATE V -

showing ratio between field current and amperes output for the alternators operating at the proper speed was taken, and curves plotted as shown on plate II and III. Starting the test with driving forces equal, at no load, the current division was determined for all loads both with and without transformers: page 19 . In both cases the driving forces were allowed to change according to the motor load-speed characteristics. Again the use of transformers showed more exactness in dividing the current, and better still was the division with transformers, the driving forces having been accurately adjusted thruout the run: page 21.

In test No. 2, pages 24 and 25, the number of lamps was kept constant to give about 30 amperes output for each alternator. Starting with driving forces equal, the current division was determined for values of field current of alternator No. 2 varying from .88 to 1.60 amperes, while the excitation on alternator No. 1 was kept constant. Normal excitation on alternator No. 2 was 1.32 amperes for this load. Calculations of the current output of alternator No. 1 in per cent of the total current, and the resulting curves, plate VI, show a decidedly better division of the load current when transformers were used than when they were not used. The average voltage, however, dropped from 115 volts to 90 volts with a change of field excitation from 1.60 to .88 amperes when transformers were used, showing a much poorer regulation than the drop to 97.5 volts without transformers for a corresponding change in excitation.

Test No. 3, page 28, was run with constant load and constant field excitation, and with an increasing driving force

—Data for Current Load Division—

Load constant, with field excitation no. 2 varying.

—With Transformers—

Field Current of no. 1 equal to 4.11 Amp.

No. of Reading	Alternator No. 1				Alternator No. 2				Current thru Reactance Coil in Amperes.
	Current Output Amp.	Power Output K.W.	Pressure in Volts	Amp. Output in % of Total Amp.	Current Output Amp.	Power Output K.W.	Pressure in Volts	Field Current Amp.	
1	30.6	3.51	110.0	51.5	28.9	3.19	109.0	1.32	2.0
2	31.0	3.54	111.3	51.2	29.6	3.30	111.3	1.40	5.0
3	32.1	3.74	114.0	51.7	30.0	3.43	114.0	1.50	6.2
4	32.2	3.74	115.2	51.5	30.2	3.58	115.2	1.60	8.6
5	29.5	3.29	109.0	50.0	29.5	3.27	108.0	1.25	2.0
6	28.7	3.15	106.0	50.2	28.5	3.03	104.5	1.15	1.0
7	28.2	3.02	103.3	50.2	28.0	2.88	102.0	1.10	2.5
8	27.5	2.78	101.5	50.4	27.0	2.70	100.0	1.05	5.6
9	25.9	2.61	99.0	49.5	26.4	2.61	97.5	1.01	7.2
10	25.6	2.58	97.0	49.9	25.7	2.45	95.2	.98	8.9
11	25.3	2.38	94.0	50.3	25.0	2.25	91.5	.92	11.0
12	24.6	2.29	93.0	49.8	24.8	2.21	90.0	.90	11.6
13	23.2	2.16	91.5	48.5	24.5	2.16	88.0	.88	12.4

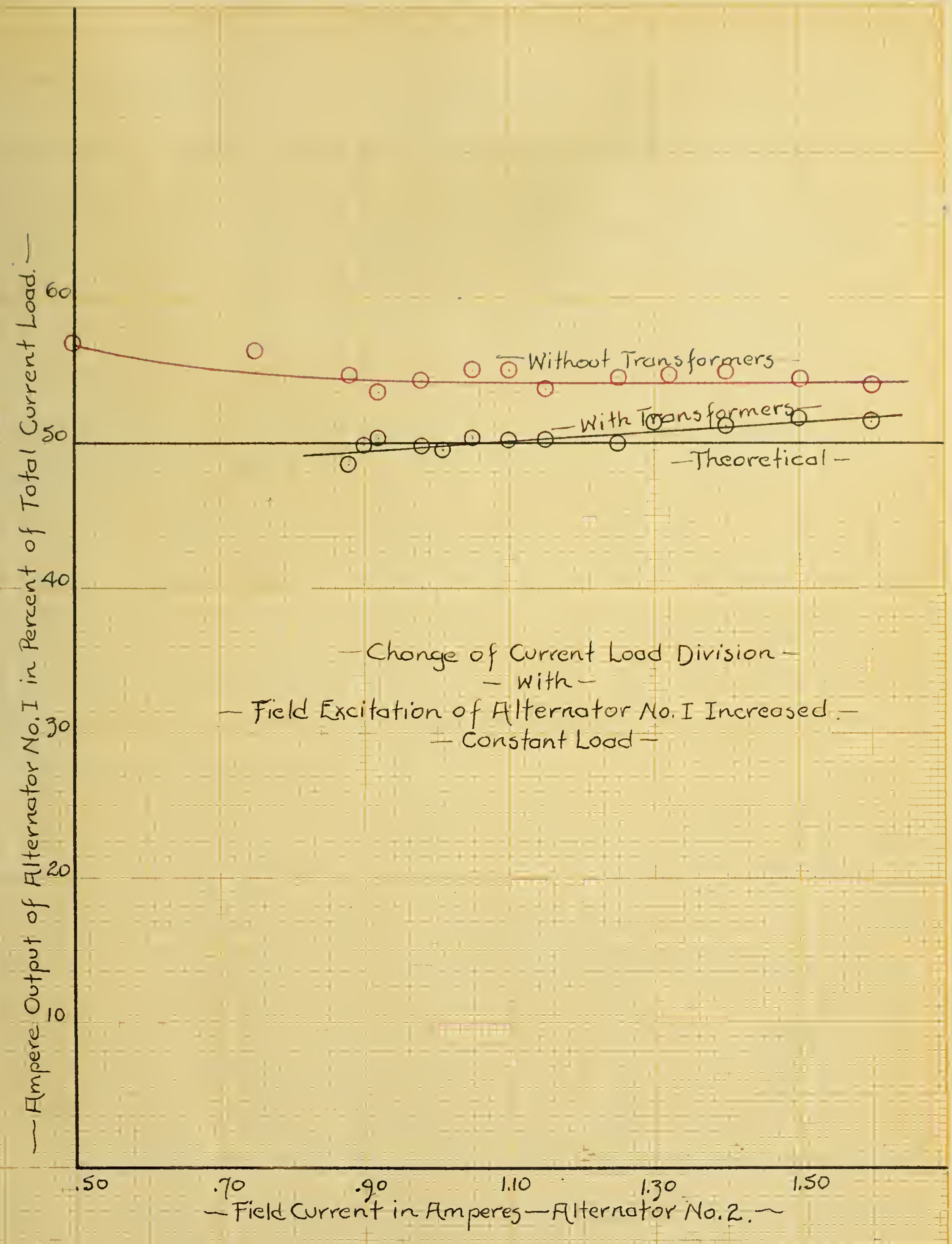
-- Data for Current Load Division --

Load constant; with field excitation of no. 2 varying.

— Without Transformers. —

Field Current of no. 1 equal to 4.11 Amp.

No. of Reading	Alternator No. 1				Alternator No. 2				Current thru Reactance Coil in Amperes.
	Current Output Amp.	Power Output K.W.	Pressure in Volts	Amp. Output in % of Total Amp.	Current Output Amp.	Power Output K.W.	Pressure in Volts	Field Current Amp.	
1	33.5	3.95	117.0	54.0	28.6	3.21	114.2	1.60	0
2	33.6	3.97	116.4	54.4	28.2	3.19	113.5	1.50	0
3	33.0	3.80	114.2	54.9	27.1	3.00	111.3	1.40	0
4	32.2	3.68	112.0	54.6	26.8	2.90	109.5	1.32	0
5	31.3	3.48	108.5	54.5	26.0	2.74	105.8	1.25	0
6	30.0	3.27	106.5	53.6	26.0	2.69	104.2	1.15	0
7	30.7	3.26	106.1	55.0	25.2	2.59	103.4	1.10	0
8	30.2	3.18	104.8	55.0	24.8	2.46	102.3	1.05	0
9	29.0	2.98	102.2	54.3	24.4	2.37	99.8	.98	0
10	27.8	2.81	100.6	53.5	24.2	2.31	97.6	.92	0
11	28.2	2.82	98.8	54.7	23.3	2.17	96.2	.88	0
12	27.7	2.62	94.4	56.4	21.4	1.96	91.7	.75	0
13	24.5	2.08	85.0	56.9	18.6	1.48	81.5	.50	0


60
50
40
30
20
10
— Ampere Output of Alternator No. I in Percent of Total Current Load. —
.50
.70
.90
1.10
1.30
1.50
— Field Current in Amperes — Alternator No. 2. —
— Without Transformers —
— With Transformers —
— Theoretical —
— Change of Current Load Division —
— with —
— Field Excitation of Alternator No. I Increased —
— Constant Load —

— PLATE VI —

on alternator No. 1, that on alternator No. 2 being constant. In order to obtain readings both with and without transformers for exactly the same condition of driving forces, the readings with transformers were secured first, and then the transformer primaries were short circuited and cut out of circuit by means of the switches, S_{sc} and S_{co} to secure the other readings. In this case the curves on plate VII show that with a great difference in the driving forces, the current division changed, the larger load going to the machine of greater driving force. This was more true with transformers than without them. Plate VIII shows a slight rise in voltage as the driving force on alternator No. 1 was increased when running without transformers, and a most decided drop when transformers were used, showing that as the difference in current became greater, the impedance of the transformers increased..

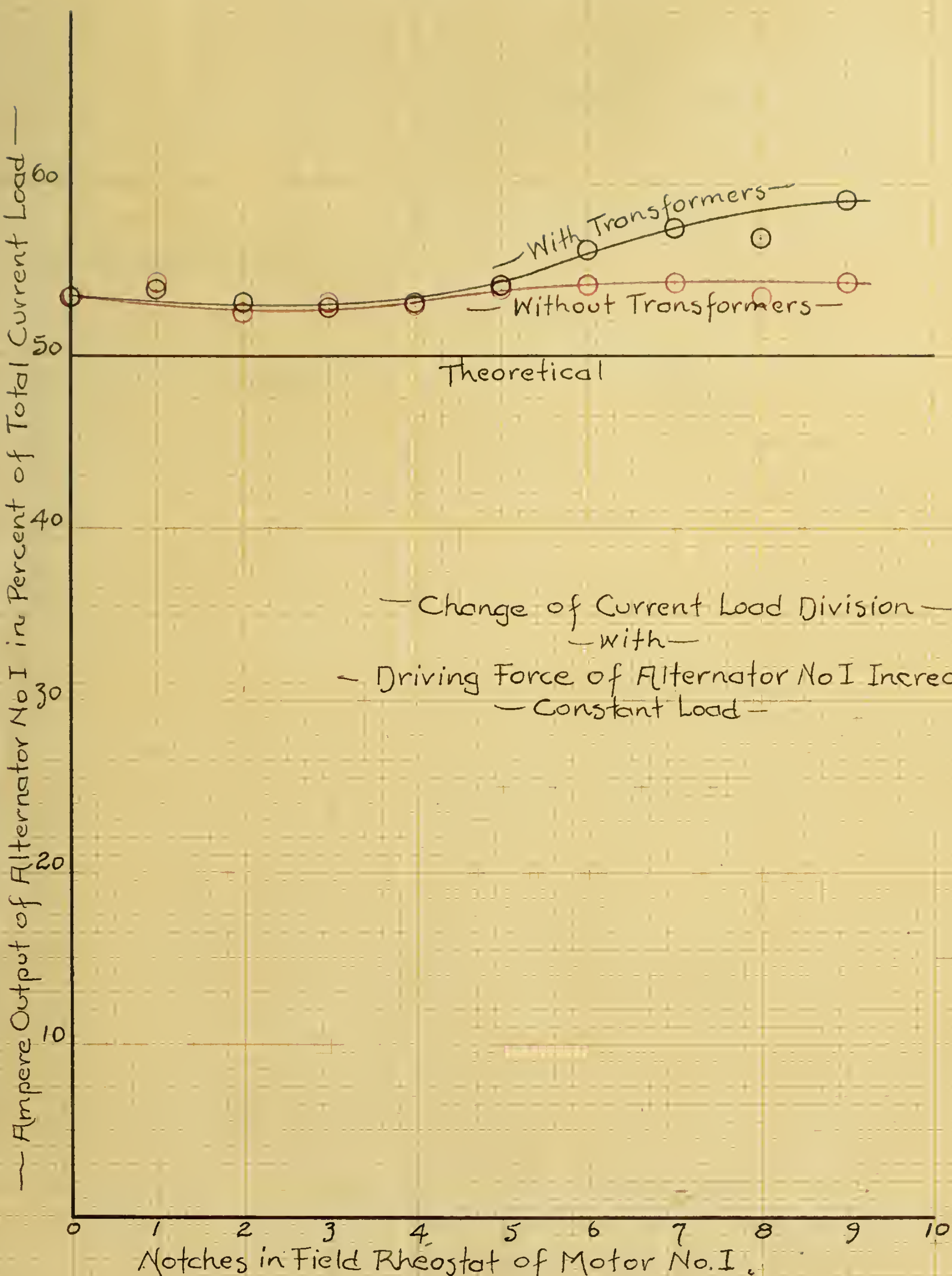
To test a 2 to 3 ratio of current division, the primary coil of one transformer was placed in the lead of alternator No. 1, and the secondary coil in the corresponding lead of alternator No. 2. Alternator No. 2 should therefore have assumed three fifths of the current load, but the data and curves, pages 31 and 32 show a nearly equal division of current load. Having started with driving forces equal at no load, they remained nearly so thruout the test, because the load speed characteristics of the motors are quite similar. This equality of driving forces would not allow the division of current in another ratio.

In all tests, alternator No. 1 assumed a larger current load than alternator No. 2. To determine if this was due to a difference in the transformers, a primary-secondary current ratio

— Data for Current Load Division —

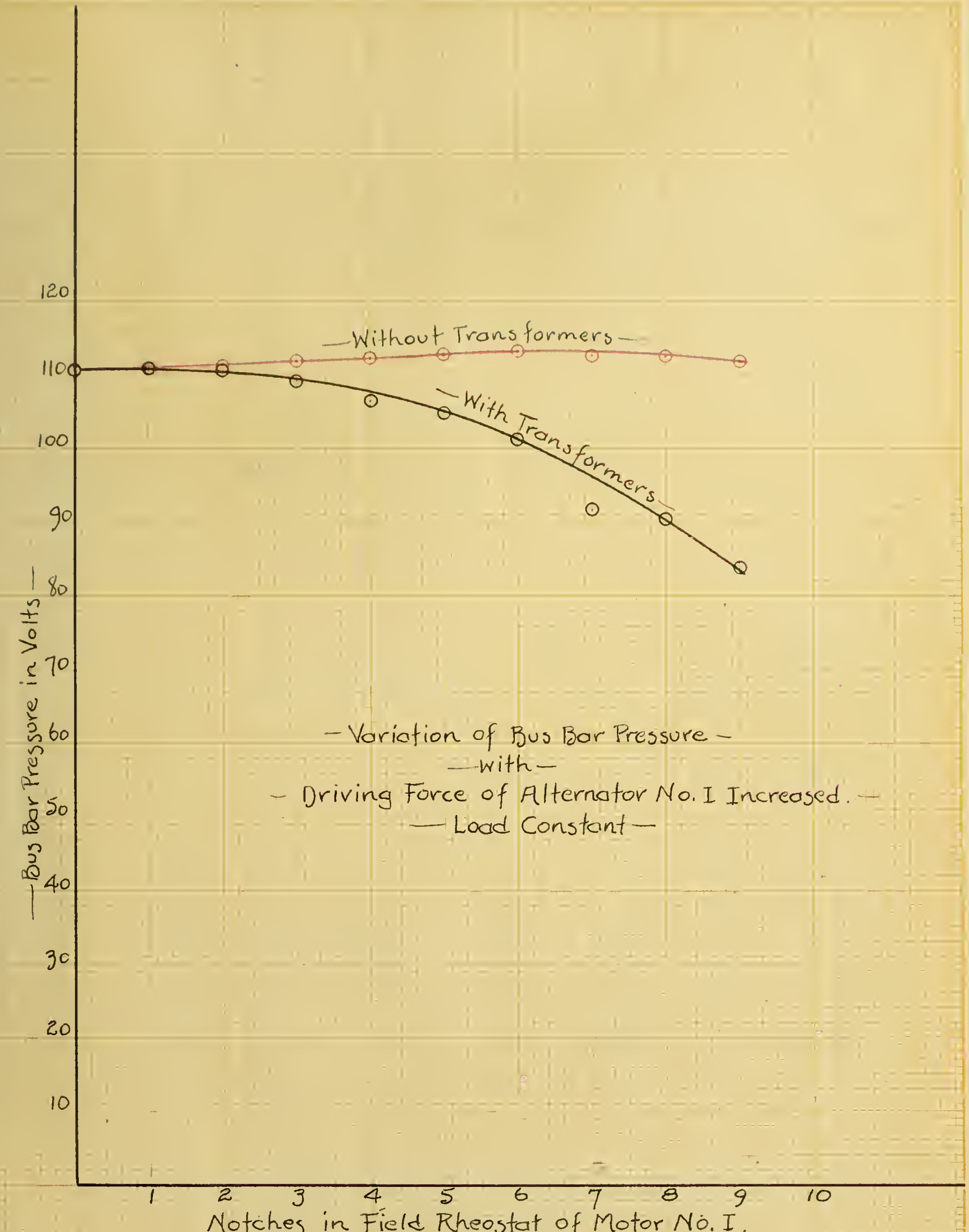
Load constant; driving force on No 1 increased, with excitation constant. "a", with transformers; "b", without tran's.

Number	of Reading	Alternator No. 1 Current Output Amps.	Alternator No. 1 Power Output K.W.	Alternator No. 1 Pressure in Volts	Alternator No. 2 Current Output Amps.	Alternator No. 2 Power Output K.W.	Alternator No. 2 Pressure in Volts	Current thru Reactance Coil in Amperes.
1	a	31.2	3.43	111.5	27.2	2.94	110.0	1.0
	b	31.6	3.54	111.5	27.6	3.04	109.5	0
2	a	31.5	3.55	111.5	27.1	2.95	110.5	5.4
	b	32.0	3.66	112.0	27.0	2.95	110.0	0
3	a	30.9	3.48	110.5	27.3	2.97	110.5	6.7
	b	31.8	3.56	112.3	28.8	3.18	110.0	0
4	a	30.2	3.32	109.0	27.0	2.96	109.0	10.4
	b	31.7	3.64	113.2	28.2	3.10	110.6	0
5	a	29.4	3.18	105.6	25.9	2.74	106.8	14.3
	b	31.9	3.64	113.4	28.4	3.12	111.2	0
6	a	29.5	3.12	104.3	25.0	2.59	105.4	16.4
	b	32.4	3.78	114.0	27.8	3.09	111.0	0
7	a	28.9	2.79	100.0	22.6	2.30	102.0	20.2
	b	32.5	3.76	114.5	27.6	3.02	111.7	0
8	a	27.1	2.51	90.5	20.0	1.92	92.3	24.2
	b	32.6	3.74	114.2	27.5	3.05	111.0	0
9	a	26.2	2.33	89.5	19.9	1.88	91.1	25.4
	b	32.0	3.71	114.0	28.0	3.04	110.5	0
10	a	24.8	2.05	83.5	17.1	1.57	84.0	28.4
	b	32.4	3.80	113.2	27.2	3.05	110.3	0



— Change of Current Load Division —
— with —
— Driving Force of Alternator No I Increased. —
— Constant Load —

-PLATE VII-


120
110
100
90
80
70
60
50
40
30
20
10
—Bus Bar Pressure in Volts—
—Without Transformers—
—With Transformers—
—Variation of Bus Bar Pressure—
—with—
—Driving Force of Alternator No. I Increased.—
—Load Constant—
1
2
3
4
5
6
7
8
9
10
Notches in Field Rheostat of Motor No. I.

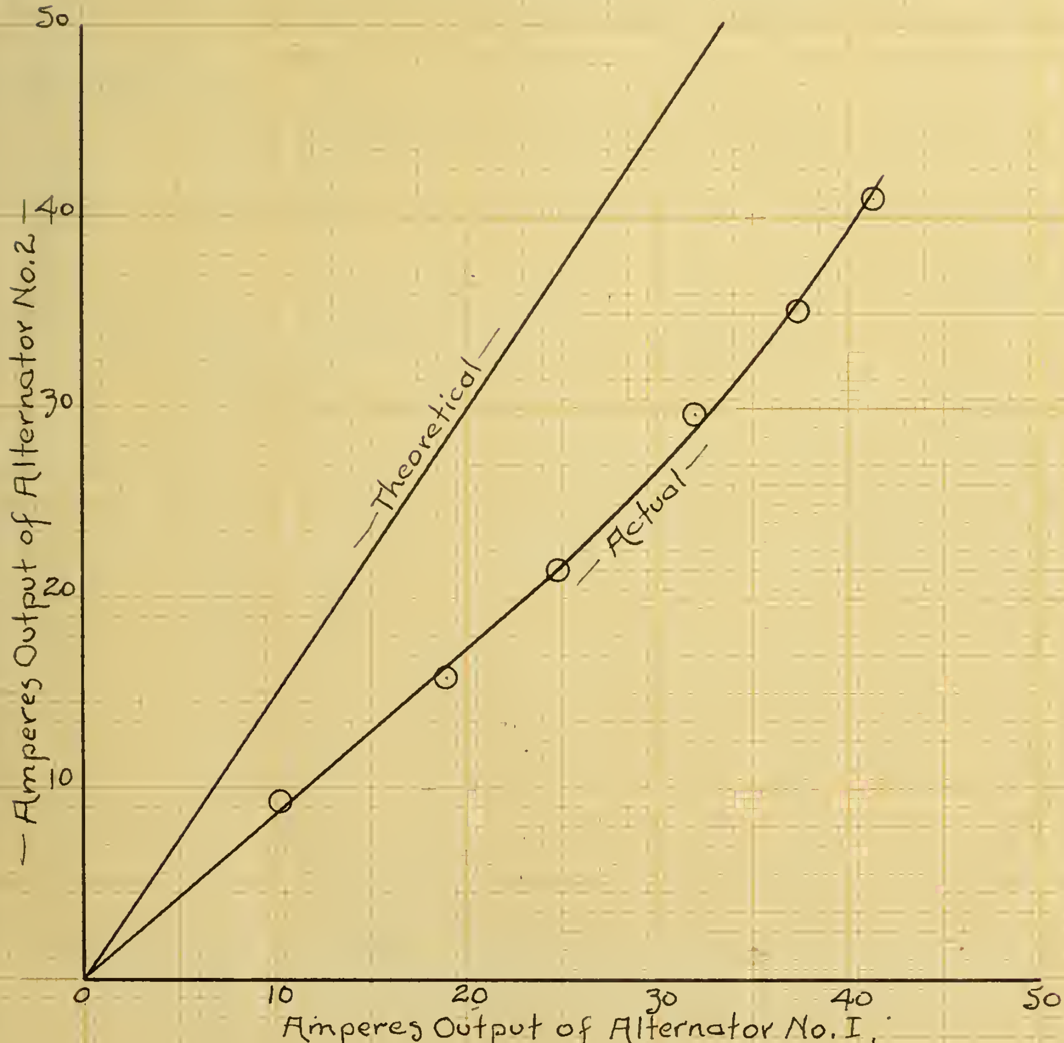
—PLATE VIII—

—Data for Load Current Division—

Theoretical Ratio:— Current Output of no. 1 is to current output of no. 2 as 2 is to 3.

No. of Reading	Alternator No. 1			Alternator No. 2			Current thru Reactance Coil in Amperes.
	Current Output Amp.	Power Output K.W.	Pressure in Volts	Current Output Amp.	Power Output K.W.	Pressure in Volts	
1	0	0	110.0	0	0	110.0	0
2	10.2	1.13	109.0	9.3	.76	109.0	0
3	18.9	2.11	107.5	15.8	1.69	107.5	0
4	24.8	2.65	105.2	21.5	2.24	105.0	0
5	32.0	3.28	102.7	29.6	3.00	101.8	0
6	36.5	3.74	101.0	35.1	3.42	99.5	0
7	41.3	4.06	98.2	41.0	3.80	96.5	0

— Load Current Division —
— with —
— Transformers Connected in a ratio of two to three. —



— PLATE IX —

test was made on the transformers. This was accomplished by running the alternators separately and short circuiting the transformer secondaries thru ammeters. For any given primary current, the secondary current of transformer No. 2 was slightly less than that of transformer No. 1. In order to have the secondary currents equal, the primary current of transformer No. 1 should have been less than the primary current of transformer No. 2, and therefore alternator No. 2 should have carried the greatest part of the current.

The characteristic curves, plate XI, show that the pressure of alternator No. 2 decreases faster as the load increases, than that of alternator No. 1. This makes the operation of the two machines in parallel less successful.

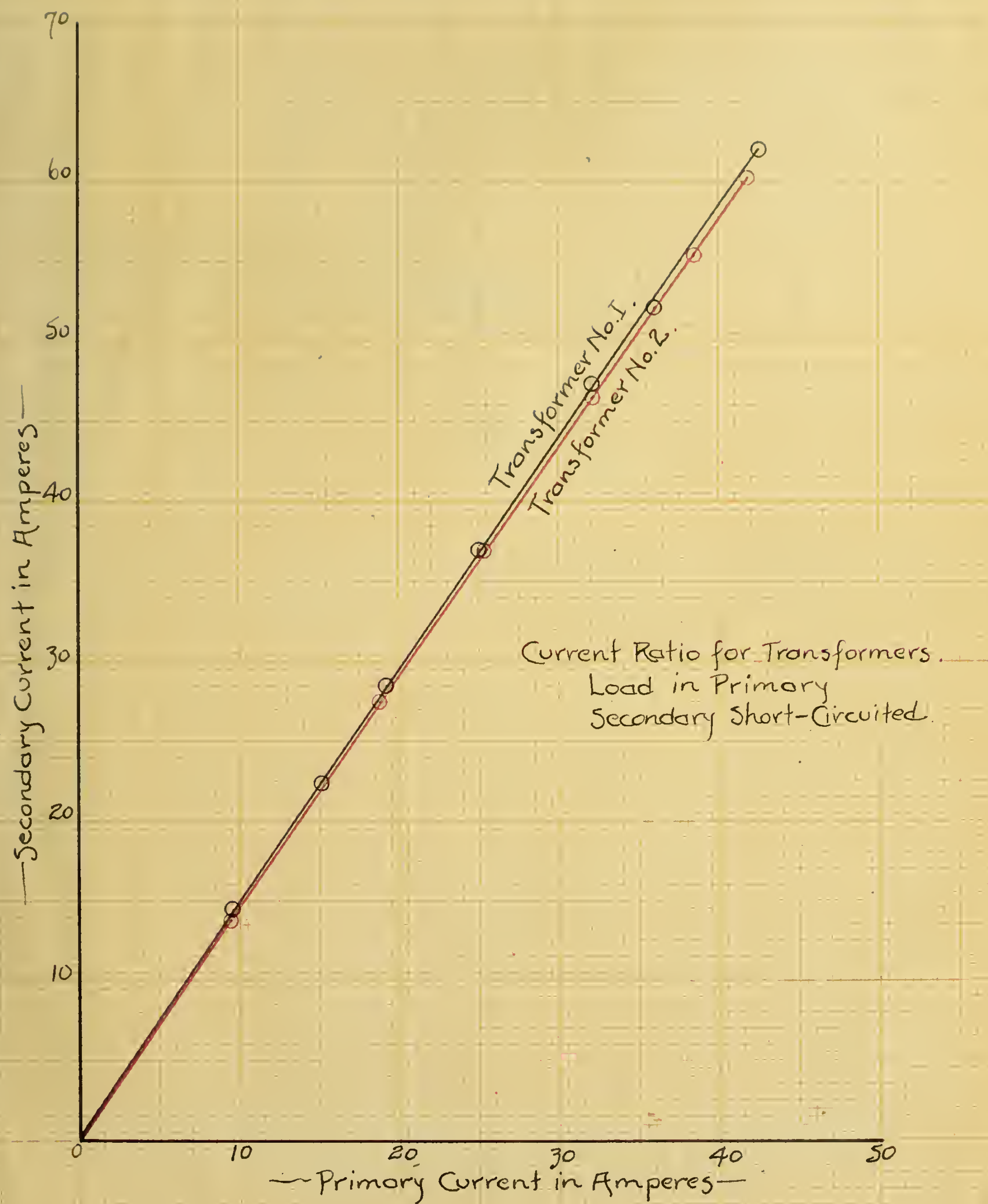
The electromotive force waves traced by means of the oscillograph are shown to be so greatly different in form that they also add difficulties to the successful parallel operation of the two alternators.

-- Data for --

Transformer Current Ratios

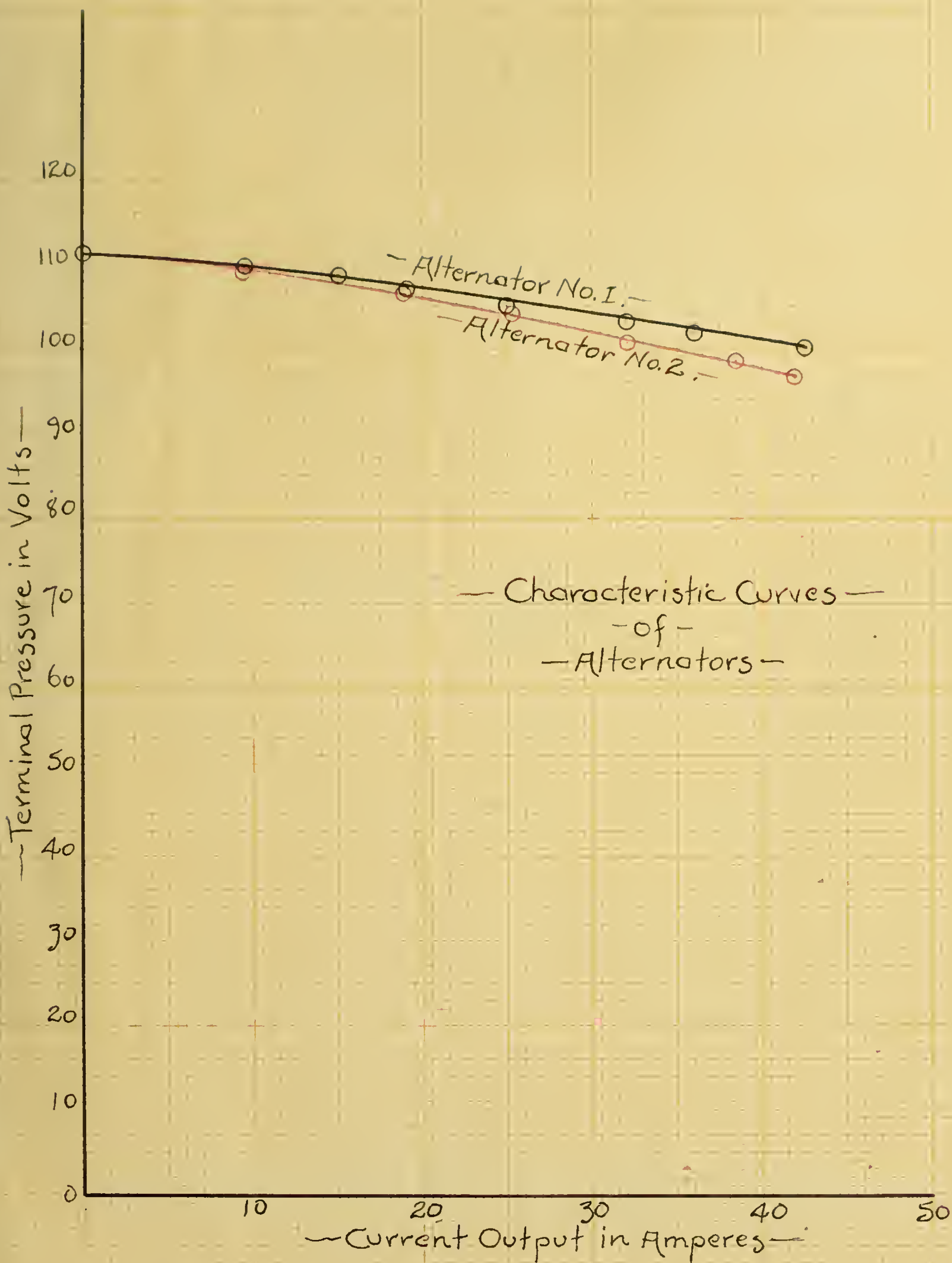
and for Alternator Characteristics.

-No.1-				-No.2-		
Primary Current Amp.	Secondary Current Amp.	Alternator Pressure Volts.		Primary Current Amp.	Secondary Current Amp.	Alternator Pressure Volts.
0	0	111.3		0	0	111.3
9.5	14.5	109.8		9.4	13.8	109.0
15.1	22.4	108.5		18.8	27.5	107.5
19.2	28.5	107.0		25.3	37.0	104.0
25.0	37.0	105.0		32.1	46.4	100.5
32.1	47.3	103.6		38.5	55.3	98.5
36.0	52.0	102.5		41.9	60.2	96.3
42.6	62.0	100.0				



70
60
50
40
30
20
10
0
10
20
30
40
50
—Secondary Current in Amperes—
—Primary Current in Amperes—
Transformer No. I.
Transformer No. 2.
Current Ratio for Transformers.
Load in Primary
Secondary Short-Circuited.

—PLATE X—



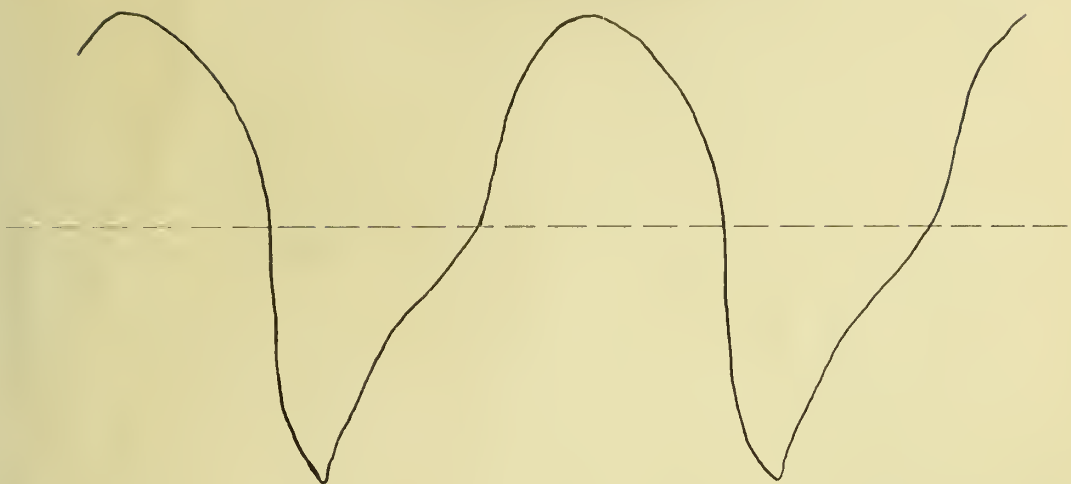
120
110
100
90
80
70
60
50
40
30
20
10
0
—Terminal Pressure in Volts—
—Alternator No. I.—
—Alternator No. 2.—
—Characteristic Curves—
—of—
—Alternators—
10
20
30
40
50
—Current Output in Amperes—

PLATE XI.

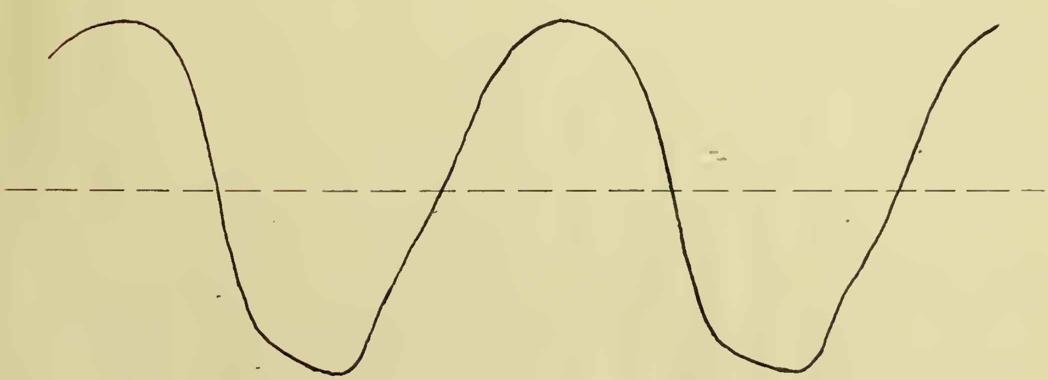
—Miscellaneous Data—

—Coils—	Resistance Ohms	Impedance Ohms
Reactance Coil --	.527	4.23
Primary -- Transformer no. 1 ---	.00574	15.89
Primary -- " no. 2 --	.00590	16.03
Secondary -- " no. 1 --	.00244	7.32
Secondary -- " no. 2 --	.00244	7.43

—Inductor Alternator.—
—Machine No. 2—



—E.M.F. WAVE FORMS—



—G.E. Alternator—
—Machine No. 1—

CONCLUSION.

It is seen that in every test except with varying drivinf forces, a better division of current was secured when the transformers were used than without them. This is due to the fact that a more exact regulation of the driving forces could be secured when the transformers were used because a slight difference in the driving forces would immediately be shown by the current flowing thru the reactance coil circuit. A still better division could have been attained if the transformers had been of smaller capacity and of more turns. As it was, the transformers never had full load current applied and the iron losses were entirely too large at the loads used in the tests. A much larger drop in pressure was caused by the transformers than without them, and this would be an objectionable feature in practical operation of alternators in parallel. The current division is almost entirely dependent upon the prime movers. It is known that the power load division is determined by the driving forces. Assuming equal voltage, when the machines are operating with unequal driving forces and consequently with unequal power load division an equal current division may be secured only by having unequal power factors. But as the load on each alternator was non-inductive, and as equal current will give similar conditions in each transformer, unequal power factors can not be secured. It follows therefore, that the current division will not be equal unless the load division isequal, and therefore not unless the driving forces are equal.